Report of the Investigation into the over-pressurisation of a cargo tank on the Oil Tanker

MOBIL PETREL

at Fawley Oil Terminal
on 7 November 1989

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1. SUMMARY

Whilst berthed at Esso Fawley Oil Terminal the Bermuda-Registered MOBIL PETREL, a 16 year old very large crude oil tanker, suffered major structural failure in two adjacent cargo tanks as a simultaneous cargo and ballast operation was under way.

A large quantity of ballast water and crude oil contained in the tanks flowed through the breached structure and flooded into the pipe tunnel, the main and auxiliary pump rooms and the engine-room. Dangerously high concentrations of hydro-carbon gas were released into the spaces and into the atmosphere.

A major incident was declared by the emergency services who co-ordinated successfully to prevent an explosion, loss of life and serious pollution to the environment.

The investigation established that structural failure was caused by over pressurisation of one of the cargo tanks as ballast water was loaded into it. An inert gas (I.G.) branch valve leading to the tank had been unintentionally operated preventing adequate venting of the tank atmosphere. The valve was in a poor state of repair causing confusion over its open and closed position.

The MAIB investigated the accident under the terms of the Merchant Shipping (Accident Investigation) Regulations 1989 and at the request of the Bermudian Administration.

A number of lessons have been learned from the investigation which relate to over pressurisation of cargo tanks and the operation and maintenance of I.G. systems. Recommendations in the report aim to prevent recurrence of a similar incident in the future.

The Inspector found malpractice in the operation of the I.G. system despite there being first class standing orders and operational manuals on board the ship, and officers with long experience of tanker operation.

The report discusses the need for more concise records of inspection, of defects found and of repairs carried out which affect the safe and efficient operation of the I.G. system so that Port State Inspectors, Surveyors and Shore Management can easily ascertain that its state of performance is in accordance with national, international and company regulations.

The catastrophic failure of the structure occurred in cargo tanks which were over one hundred and forty yards from the engine room, yet high concentrations of flammable gas, crude oil and ballast water from these tanks were able to penetrate into the engine-room. The report questions the adequacy of requirements which allow a pipe tunnel of the kind installed in MOBIL PETREL to connect into the cargo pump room without any need for the spaces to be isolated from each other during operation of the ship. If the pump room access to the pipe tunnel had been closed and watertight at the time of the incident the extent of flooding and the potential danger of explosion and fire would have been significantly reduced.

Oil Tanker Mobil Petrel

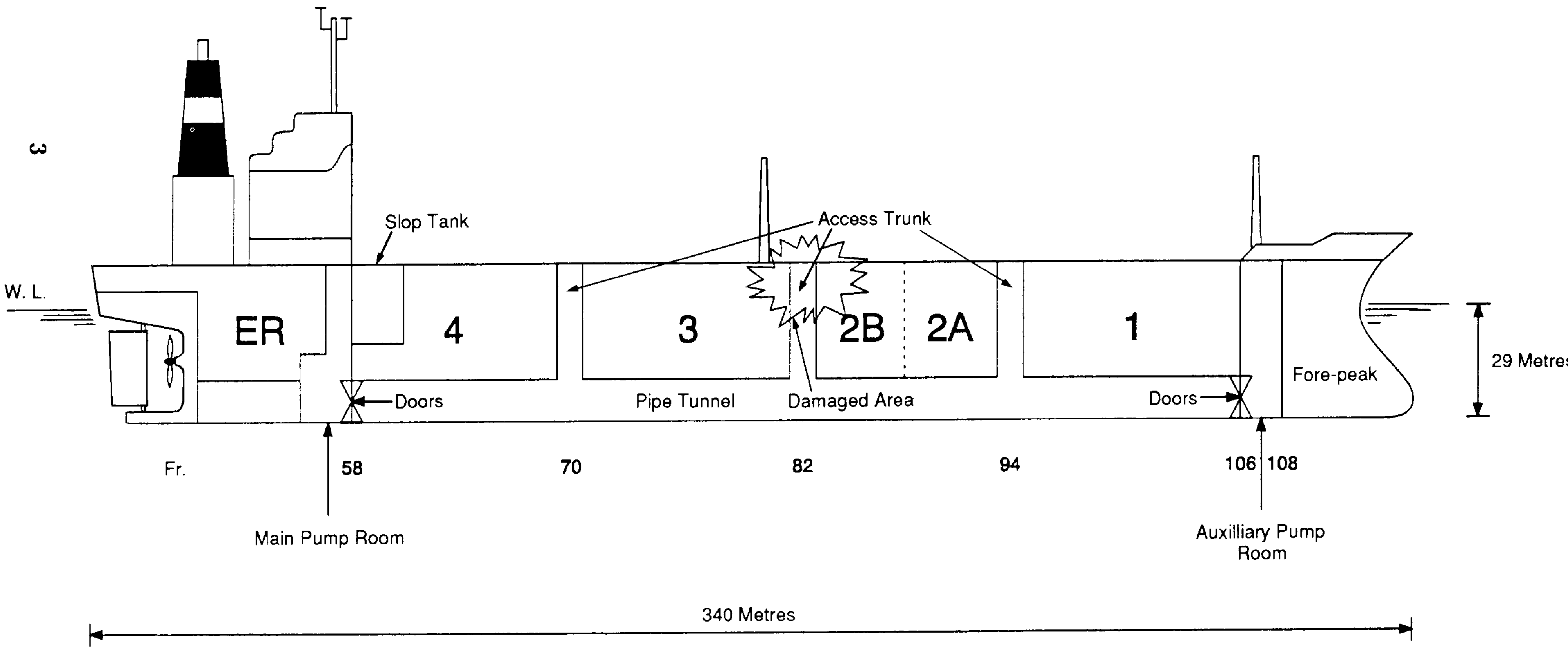


Fig. 1

PART I FACTUAL ACCOUNT

2. PARTICULARS OF SHIP

2.1 Background

MOBIL PETREL, a very large crude oil carrier, ON 710488, Port of Registry Hamilton, Bermuda, is owned by Mobil Overseas Shipping (Bermuda) Limited, Commerce Building, Reid Street, Hamilton, Bermuda. The ship is demise chartered to Mobil Shipping and Transportation Company, New York, and is managed by Mobil Shipping Company Limited, London under the terms of a service contract with Mobil Shipping and Transportation Company. At the time of the incident the ship was on voyage charter by Mobil Shipping and Transportation Company to Esso International Shipping (Bahamas) Company Limited.

Mobil Shipping Company Limited are at Mobil Court, 3 Clements Inn, London, WC2A 2EB.

2.2 Description and Construction of the Ship

The vessel was built by SASEBO HEAVY INDUSTRIES Company Limited, Japan in 1973, and is classed by American Bureau of Shipping and entered into their record as +A1 OIL CARRIER and +AMS. The principal dimensions are as follows:-

Length BP (m)	327.066
Breadth, moulded (m)	53.569
Depth, moulded (m)	28.00
Gross tonnage	133,560
Summer Deadweight (tonnes)	280,326

The ship is an all steel welded vessel with a bulbous bow. The bridge, accommodation and machinery spaces are sited aft.

It is powered by a geared steam turbine installation connected to a single propeller shaft which develops 30,000 shaft horse power. Auxiliary power is provided by two 320kW turbo alternators. The emergency electric power is supplied by a 340kW diesel alternator positioned in the superstructure on the Upper Deck level on the starboard side of the vessel.

Two longitudinal bulkheads divide the wing tanks from the centre tanks. For cargo purposes there are five centre tanks and four wing tanks on each side. Three slop tanks are stepped into the after end of the most aft centre tank. The structural steel work is restricted where possible to the wing cargo tanks so that the large centre cargo tanks are flat sided and easily cleaned.

A double bottom structure is incorporated into the hull throughout the length of the cargo tank spaces. The structure is divided into four port and four starboard tanks, separated by a duct keel pipe tunnel. These tanks are used exclusively for water ballast. All ballast, cargo, bilge and other service pipes and valves and electrical lighting cables pass along the pipe tunnel and hence are relatively accessible for examination, overhaul and repair.

The openings leading into the cargo tanks are the conventional tank hatches, the tank cleaning openings, the tank sounding pipes with a vapour locking device, the high and low level electrical probes, and the crude oil washing (COW) pipelines. The air pipes to the double bottom tanks pass through the cargo tanks.

A small drain well is recessed into the tank bottom at the aft end of each cargo tank and a single pipe from the pipe tunnel leads into the well. This single pipe is used for all the cargo tank duties such as filling, discharging, ballasting and stripping and the control valve, of the butterfly type, arranged for remote hydraulic control from the cargo control room (CCR), is interposed in the line within the pipe tunnel and set back some few feet from the cargo tank drain well.

The main pump room contains four cargo pumps, one water ballast pump, two ventilation fans, stripping pumps, COW eductors and other cargo handling equipment. The horizontal drive shafts for each fan and pump unit penetrate the watertight bulkhead which separates the pump room from the engine-room. These bulkhead penetrations use a conventional fibre gland packing arrangement in order to maintain gas and water tightness.

Forward of the cargo tanks and double bottom tanks is the auxiliary pump room, two fuel oil deep tanks, a chain locker and a forepeak ballast tank.

The remaining part of the ship's structure situated aft of the main pump room is taken up by fuel oil settling tanks recessed into the after part of the main pump room, fuel oil bunker tanks, machinery spaces, an afterpeak water ballast tank and freshwater tanks.

Entry into the pipe tunnel can be gained from the main pump room and auxiliary pump room spaces through steel doors, two at either end, each secured by eight individual dog latches, which can be operated from either side of the door. These doors are designed and fitted in accordance with Classification Requirements and are similar to access openings in bulkheads of enclosed superstructures.

Three vertical pipe tunnel access trunks, each leading into a deck house accessed by a weathertight door, run up the after side and on the centre line of a main transverse bulkhead. There is an open access from the bottom of each trunk into the pipe tunnel.

A bilge level alarm is fitted in the CCR. The alarm is incorporated in a single unit with a probe in the main pump room and one in the aft end pipe tunnel. The alarm does not indicate which probe is activated.

For ventilation purposes the auxiliary pump room and the pipe tunnel make up one common space. Two steam driven exhaust fans situated in the forecastle above the auxiliary pump room draw air from outside on the aft main deck down a central ventilation trunk which leads vertically downwards along the main pump room forward transverse bulkhead and into the aft end of the pipe tunnel. The air is drawn along the pipe tunnel and into two separate ventilation trunks leading upwards through the auxiliary pump room to the exhaust fan intakes. A branch connection in the trunks draws air in from the bottom of the auxiliary pump room. Fire flaps at the open end of each branch connection can be closed from a remote position in the forecastle.

The main pump room is ventilated using two fans, one of which is an exhaust fan and the other a forced draft fan. The exhaust fan takes in air from a number of trunk branch openings situated at the bottom of the pump room and exhausts through a single trunk out onto deck through a ventilation cowl. The forced draft fan can be used to ventilate the tunnel and auxiliary pump room with the tunnel doors open and main pump room entrance door closed. Each of the fan trunk openings on the deck can be shut down by hand operated lever fire dampers.

2.3 The Gas Venting System

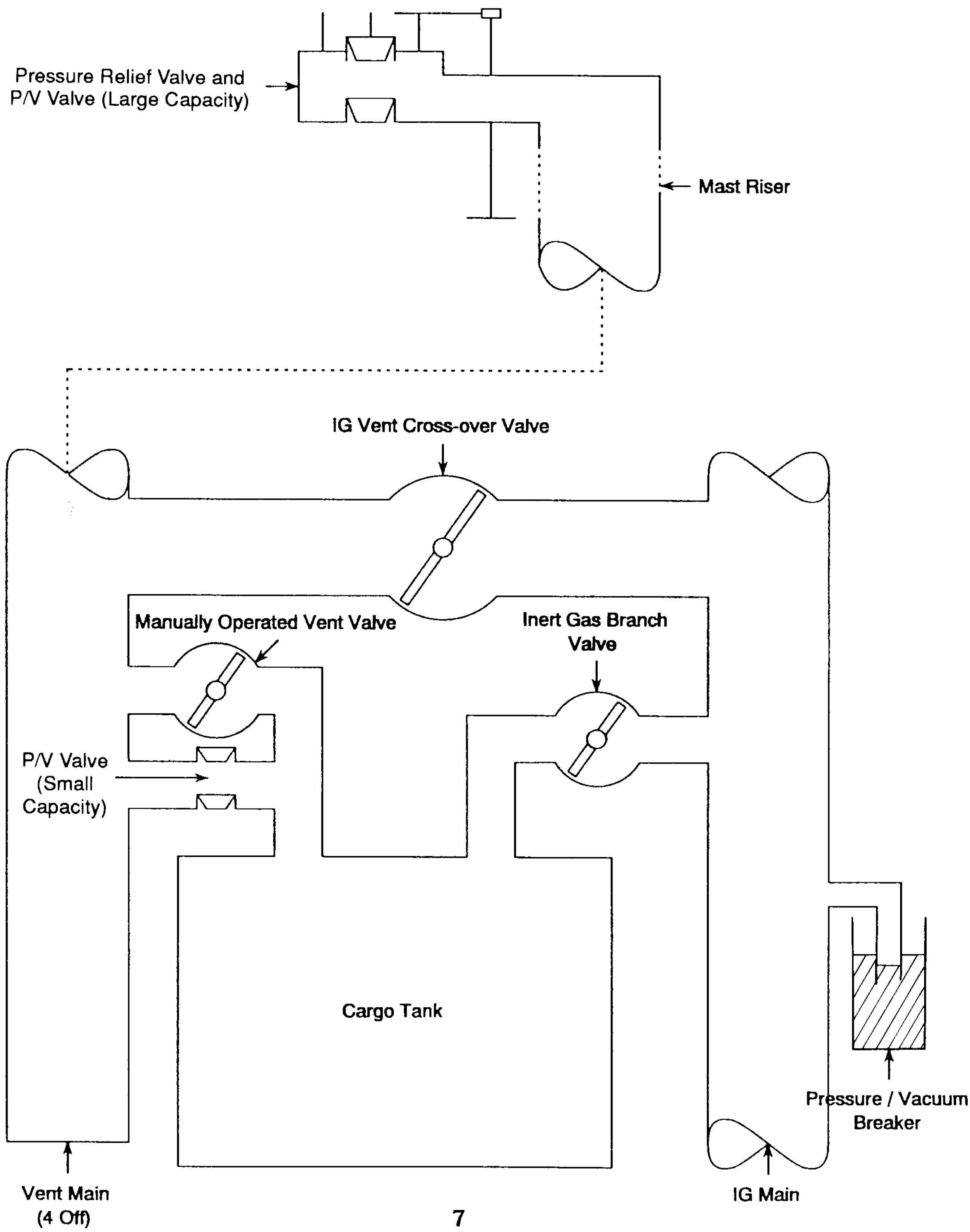
The gas venting system [Fig 2] consists of four separate common vent mains which run along the length of the main deck. Branch pipes lead from the top of each of the cargo and slop tanks into one of the mains. Each vent line is fitted with a manually operated butterfly valve (vent valve) around which is a smaller bore line fitted with a pressure vacuum valve (p/v valve). The p/v valve is designed to control pressure variation in the tank caused by ambient temperature changes; it can be jacked into an open position or set to operate automatically.

Each common vent main leads to a mast riser and exits at the mast head through a high capacity pressure relief valve. A high capacity vacuum relief valve and flame arrestor is fitted adjacent to this unit. The pressure relief valve can be jacked open from a remote position on deck at the base of the mast, or operated automatically as cargo or ballast is pumped in or out of the tanks.

A hydrostatic pressure relief valve is fitted on the vent main lines at the base of each mast riser.

Oil Tanker Mobil Petrel
Cargo Tank Vent and IG Arrangements

Fig. 2



2.4 The Inert Gas System

The I.G. system was retrofitted in 1975 and surveyed and certificated by American Bureau of Shipping (ABS). It satisfied the relevant regulations in the Merchant Shipping (Fire Protection) (Ships Built Before 25 May 1980) Regulations 1985 which apply to Bermuda-registered vessels.

The I.G. supplied by the main boiler plant, is maintained at a constant pressure by a pressure regulating valve operated by a control air gas pressure transmitter regulator.

Gas not required in the cargo tanks is recirculated back to the scrubber through a dead weight controlled regulating valve, or can be vented through a hand operated cross over valve which isolates the I.G. deck main from one of the four common cargo tank vent mains (common vent mains) and out to atmosphere through the respective mast riser and pressure relief valve.

The gas replacement in the cargo and slop tanks is by means of the dilution method when I.G. enters at the top of the tank and mixes with the original gases in the tank which are displaced out into the common vent main.

At the point of entry of the I.G. into each tank, a single hand operated geared butterfly valve isolates the tank from the I.G. main distribution pipeline. The valves should be capable of being locked in the open or shut position.

2.5 Cargo Control Room

The accommodation and the bridge are situated aft above the main machinery space, the accommodation being arranged in a five tier deck house structure. The CCR is located in the accommodation on the boat deck. Access to the CCR is through a steel door on the cross alleyway of the accommodation. Fitted in the CCR is the I.G. pressure control and alarm system, the cargo and ballast hydraulic valve actuation system, the I.G. distribution valve status board and the tank gas level status board.

The loading computer is situated in the cargo office, next door to the CCR and is used to assess hull stresses for different patterns of cargo and ballast distribution.

2.6 Fire Fighting Equipment

The equipment satisfies the relevant requirements in the SOLAS 1974 convention and in the Merchant Shipping Regulations relating to Bermuda-registered ships.

In particular, on deck, there is a conventional water fire main and a fixed foam fire main system. Water is supplied by a steam turbine pump and electric pump which are situated in the engine-room, and by a diesel/hydraulic pump in the forecastle.

A fixed foam fire smothering extinguishing system is fitted in the engine-room and a sprinkler system is installed in the pipe tunnel which receives water from the deck fire main.

2.7 Certificates

Cargo Ship Construction Certificate;	
expiry date	28.02.93
Issued by ABS, London	15.08.88
Annual Survey by ABS, Singapore	14.01.89
Cargo Ship Safety Equipment Certificate;	
expiry date	23.01.90
Issued by Government of Bermuda, Hamilton	07.10.88
Intermediate Survey by ABS, Singapore	04.01.89
International Load Line Certificate;	
expiry date	28.02.93
Issued by ABS, New Jersey, USA	15.01.88
Annual Survey, Singapore	15.01.89
Cargo Ship Radio Telegraphy Certificate;	
expiry date	04.01.90
Issued by Government of Bermuda Hamilton	09.01.89
International Oil Pollution Prevention Certificate;	
expiry date	28.02.93
Issued by ABS, New Jersey, USA	15.08.88
Annual Survey	19.04.89

3. NARRATIVE

3.1 Events in Rotterdam and on Passage to Fawley

MOBIL PETREL berthed in Rotterdam at 2000 hours on 2 November 1989 with a full cargo of Arabian Light Crude loaded at Sidi Kerir. About half the cargo was discharged at Rotterdam with the balance to be discharged at Fawley.

The programme of cargo oil discharge, ballasting and de-ballasting and the COW sequence of operations followed the Chief Officer's cargo plan till 1005 hours on 3 November when a slight leakage of crude oil from a crack in the hull plating on the Number 1 port wing cargo tank was observed. The leak was discovered by the ship's Chief Engineer, who noticed it from the deck of an oil tender barge as he supervised the fuel oil bunker transfer operation.

This cargo tank was fully loaded with crude oil and it had been planned to discharge it at Fawley. The Chief Officer's cargo plan was therefore amended and the head of oil above the area of the leak was removed and the tank eventually discharged of its contents.

A minor pollution incident occurred, but the Dutch port authorities took no action after their investigation.

The local ABS Classification Society Surveyor examined externally the hull plate fracture. The Society agreed that the ship could sail from Rotterdam to Fawley, then on to Falmouth for repairs to the plate.

The pollution incident prompted the attendance on board of the Marine Superintendent Manager, from Mobil's London Office. It was his duty to ensure that the incident was handled in a satisfactory manner and that the effect of any further problems arising was minimised.

The Marine Superintendent Manager was aware that the Master, and the Chief Officer were relatively new to their ranks. The Master was on his second assignment, and the Chief Officer had been promoted only three weeks earlier. Although confident that both officers were fully capable of performing their tasks, the Marine Superintendent Manager felt that management support for the forthcoming call at Fawley would be appropriate. He therefore sailed with the ship.

Whilst in Rotterdam the vessel was joined by an officer who, on arrival at Fawley, would take over the duties of the Second Officer. As this officer was new to the Company, he was to assist the existing Second Officer with his duties as Cargo Officer of the Watch during the handover period.

At 1730 hours on 3 November the agreed quantity of cargo was received by the Rotterdam terminal. The maximum trim experienced was between 11 and 12 metres at completion of the discharge.

In order to obtain the necessary departure draught and trim, internal transfer of cargo oil and the ballasting of the forepeak tank took place. This operation was completed at 0215 hours on 4 November and at 0542 hours the ship left the berth bound for Fawley.

Before departure and when all cargo and slop tanks were pressurised with I.G., the system was shut down and the I.G. branch valves on each tank closed. On MOBIL PETREL it was normal practice to isolate inerted tanks from the I.G. main on a sea passage.

The I.G. cross over valve to the common venting system was closed, the p/v valves on the tanks and on the mast risers set on automatic and the cargo tank vent valves were shut.

No internal transfer of cargo took place on the crossing to Fawley and the ship arrived at its destination with a draught forward of 14.15 metres and a draught aft of 13.85 metres.

The Chief Officer used the loading computer to monitor the degree of hull stresses during the cargo discharge, ballasting and cargo transfer operations. He was satisfied that the maximum stresses imposed on the hull structure in the harbour condition at Rotterdam and on passage to and arrival at Fawley were within the safe stress limits set for the ship.

3.2 Events in Fawley Leading to Incident

On arrival at Fawley the status of the I.G. system and the common venting system had not been changed since the vessel's departure from Rotterdam, apart from the repair en route of a leaking expansion coupling on the I.G. mains.

The ship was secured at 1712 hours on 5 November. The Exxon Contract Inspector boarded to assess the ship and crew for suitability for future Exxon charter contracts and the Esso Vessel Inspection Officer (VIO) completed the arrival safety check list jointly with the Chief Officer. Both were satisfied that the necessary safety precautions had been taken in accordance with Esso terminal regulations. The VIO advised the Chief Officer of the Esso terminal requirement to keep the venting of cargo tanks to a minimum and that 20 minutes notice should be given of the intention to vent. Venting should not continue for more than 10 minutes if possible.

A cargo surveyor checked ullages, cargo temperatures and water content by dipping through the vapour locks, but the tanks had to be depressurised because of difficulty in taking cargo samples. The Chief Officer was unable to drop the pressure in each tank by venting the gas through the mast riser pressure relief valve despite his attempts to jack open the valve using the remote manual lever at the base of the mast.

The Master advised the Chief Officer that he should drop the pressure in the cargo tanks by venting through the ullage port of Number 1 port wing cargo tank. All the I.G. tank branch valves were, therefore, opened so that all cargo tanks were common to the I.G. main. Once the tank pressures were reduced, the cargo surveyor was able to complete his collection of cargo samples. The Chief Officer and the Third Officer closed the I.G. inlet valves to each tank and by 2230 hours the cargo figures and cargo sampling were complete. At 2300 hours, Number 1 I.G. fan was started up to re-pressurise the tanks in preparation for cargo discharge, but soon afterwards the fan tripped out when its casing failed around an area of a previous temporary repair. Number 2 I.G. fan could not be started and on investigation it was found that the supports for the filter tray in the I.G. scrubber unit had collapsed, dumping filter gravel which blocked the discharge pipe leading to the scrubber pump.

Repairs were completed at 0430 hours on 6 November and the I.G. system was started up and tested using Number 2 I.G. fan. Temporary repairs were still in progress on the casing of Number 1 fan. The I.G. was vented across to the common vent main and up the mast riser to atmosphere until the oxygen concentrations were down to between 10% and 8%. On instructions from the Chief Officer, who was stationed in the CCR, the Second Officer and the pump-man opened up the I.G. branch valves and closed the vent valves on each of the tanks to be discharged of cargo. On Number 2B centre cargo tank the I.G. branch valve could only be opened using a temporary lever attached to the gear quadrant of the valve, its gear box and hand wheel having been removed at some time past. This lever broke off in Rotterdam and the valve could only be operated using a temporary shackle and lever arrangement attached to the valve quadrant [Fig 3].

Using one cargo pump and with only Number 2 I.G. fan running the cargo discharge started at 0518 hours on 6 November. The oxygen concentration in the I.G. distribution main varied between 7.8% and 5.3% as the COW and cargo discharge operation continued into the early hours of the following morning on 7 November. At this point the cargo and COW operation ceased and the cargo surveyor inspected Number 2B centre and Number 3 wing cargo tanks and passed them as fit for ballasting. To depressurize a tank for inspection, the I.G. branch valve is closed, the vent valve is open and the mast riser pressure relief valve is open. The converse is true prior to commencing ballasting operations.

During the discharge on 6 November the current Master was relieved in command prior to going on leave.

Fig 3A. View of No 2B Centre Cargo Tank Inert Gas Branch Valve

Fig 3B. Different View of No 2B Centre Cargo Tank Inert Gas Branch Valve

Ballasting of Number 3 wing cargo tanks started at 0240 hours on 7 November and continued simultaneously with the cargo discharge and COW operation. The operation was carried out in accordance with the terminal regulations so that the I.G. displaced from the ballast tanks was passed through the I.G. distribution main and into the tanks being discharged of cargo and without any gas discharge to atmosphere. The Number 1 I.G. fan, which had been under repair, was put into use so that two fans were now in operation.

At about 0900 hours the Third Officer, who was the Cargo Officer of the Watch, informed the Master that it would take 27 hours to complete the cargo operation. The Master instructed him to put on a second ballast pump on Number 3 wing cargo tanks. The Chief Officer's original written instructions were for one pump to be used.

With effect from mid-day the existing Second Officer transferred his duties, including taking charge of the cargo watch, to the relieving Officer who had assisted him on the voyage from Rotterdam. He then went on leave.

With the ballast complete in Number 3 wing cargo tanks, ballasting of Number 2B centre cargo tank started at 1255 hours using two cargo pumps contrary to a notice in the CCR which stated that a tank should not be ballasted using two pumps at a time. The operation continued until the time of the incident.

3.3 The Incident

At approximately 1529 hours on 7 November, a loud bang was heard followed by a rumble and vibration throughout the ship. A white cloud which subsequently turned to a brown colour was released skywards from a position forward of the cargo manifold on the main deck.

The Second Officer was in the CCR and immediately tripped all the cargo pumps and started to close the cargo pump discharge valves. At the same time he instructed the pump man on deck to shut down the valves on the manifold.

Alerted by the bang, the Master and the Superintendent Manager arrived in the CCR together, followed almost immediately by the Chief Officer who had been working on the port life-boat. The bilge level alarm was sounding. It was reported to the CCR through a portable radio that the gas emission appeared to be coming from the centre tunnel access trunk. The emergency general alarm was rung and crew mustered to fire stations and all crew and visitors were accounted for. It was noted that sounding the general alarm brought order to the situation and led to an organized response with ship's personnel properly carrying out their various emergency duties. The Chief and Second Officers continued the process of shutting down the cargo system but were instructed by the Master to keep the I.G. plant running, and to monitor the I.G. panel and to keep a running log of all events. The Superintendent

Manager took charge and assumed the role of Mobil's Marine On Scene Manager, in accordance with Company Requirements, to co-ordinate on-board procedures to contain the effects of the accident. His primary concern was to avoid any conflicting orders from himself and from the Master. He made it clear that he would be in charge of the emergency response operation and that the Master would assist him. However, it was stressed that the Master would remain in command of the vessel. Ship-to-shore and internal ship-board communications were managed from the CCR, nominated as the incident room. The ship called up the emergency services on the normal telephone lines on number 999, and on Channel 19 VHF.

Fawley Refinery Marine Control were advised by the ship that an I.G. line had fractured and MOBIL PETREL had closed down its operations. Marine Control called out the tugs VECTA and CLAUSENTUM to the vessel, and advised Vessel Traffic Services (VTS) Southampton of the incident who were asked to instruct that shipping should give as wide a berth as possible to Fawley Terminal. Tankers at the refinery's berths prepared to sail.

The Hampshire Fire Brigade Headquarters were informed by Esso Fawley that an incident of possible over-pressure by I.G. had occurred in the area of two cargo tanks in MOBIL PETREL. Firemen and fire appliances were mobilised at the scene. All pump room ventilation fire flaps, and pump room housing doors were closed. Pump room and accommodation fans were stopped. The electrical supply to the pipe tunnel lighting was isolated. The initial concern was that there had been an explosion and fire in the area of Number 2B centre and Number 3 centre cargo tanks or in the access trunk at midships, or in the pipe tunnel itself. The Chief Engineer prepared the steering gear and propulsion plant in readiness to leave the berth and started up two engine-room fire pumps to supply water to the deck fire main. The pipe tunnel sprinkler system was activated. Ship's crew manned the fire monitors to direct water over the deck area around the cargo manifold and pipe tunnel access as hydro-carbon gas, evident by a shimmering haze, and I.G. continued to issue from the access hatch opening at Number 2B centre cargo tank. The Master instructed the two pump-men to close down the I.G. branch inlet valves and to open the vent valves. Shortly afterwards, the Second Officer reported that the oxygen content of the I.G. supply was running at 12% and that the I.G. pressure was hunting and reaching a maximum value of 2000 mm water gauge. The I.G. system was therefore shut down using the emergency trip.

A strong smell of hydro-carbon gas was noticed in the CCR and it appeared to be coming from a deck penetration where the hydraulic control pipes for the cargo valves entered the room from the main pump room. The hole was temporarily filled using an epoxy-resin mix.

At 1630 hours, a main pump room inspection team wearing self contained breathing apparatus (SCBA) comprising two Hampshire Fire Brigade and two Esso Fawley Fire personnel and the Chief Officer, equipped with flammable vapour detectors reported that there was no heat present in the area around the entrances to the pipe tunnel. The doors leading to the tunnel were reported to be shut with dog-latches secured in the closed position. The bilge level was sounded at 42 centimetres and was considered to be a satisfactory level under normal working conditions of the ship.

The firemen requested permission from the CCR to open a tunnel access door in order to investigate the pipe tunnel. This request was refused since it was assumed that there was an unknown quantity of oil in the pipe tunnel and that oil could penetrate into the main pump room. The situation was assessed as unstable.

Ullage measurements confirmed that the vessel was part loaded with 24,200 tonnes of cargo, 39,000 tonnes of cargo tank ballast and 31,300 tonnes of double bottom ballast. The top side of the auxiliary pump room was inspected and a concentration of hydro-carbon gas was detected in the area.

Consideration was given to the use of high expansion foam in the pipe tunnel with the intention of using the two foam generators and foam concentrate, which had already been ordered to the incident.

In the meantime engineer officers discovered hydro-carbon gas leaking through the cargo pump and ballast pump bulkhead glands into the engine-room. In an attempt to stem the leak, the air pressure in the engine-room was increased by switching the engine-room ventilation fans from low speed to high speed and by tightening and greasing the pump glands.

The Hampshire Fire Brigade connected the shore water supply to the ship's foam main and fire main using the standard international fire main couplings.

At 1850 hours oil was reported to be leaking into the engine-room from the main bulkhead glands of the cargo pumps and a cargo pump room fan. Hydro-carbon gas concentrations were reported to be high in the cargo pump area of the engine-room space. The Chief Engineer was told from the CCR to immediately shut down the main boilers and machinery in the engine room, evacuate all personnel and to report to the CCR when complete.

The engine-room ratings were ordered out of the engine-room and the Chief Engineer, the Second, Third and the two Fourth Engineers remained to secure the plant and to vent the superheated steam in the boilers to atmosphere.

In view of the developing situation the Chief Engineer felt it would be prudent to test the emergency diesel generator in order to assure himself that it was actually working correctly, prior to securing the main plant. He sent a Fourth Engineer to do this who reported to him that he had started the unit in local manual control, ran it for a few minutes, stopped it, and returned the control to its normal automatic starting position.

Once the main turbo-alternator was shut down the emergency diesel generator started automatically, but power was not transferred to the emergency switchboard. When the Chief Engineer investigated this he found the generator's automatic circuit-breaker in the open position. He closed this manually and power was then transferred to the emergency switchboard and lighting services to the ship were restored. Later, the emergency diesel generator stopped automatically because of a faulty high temperature probe in the cooling water system resulting in a total black-out on board.

The principal concern at the time was the crude oil going into the engine-room and the possibility of its vapours igniting should they come into contact with the hot surfaces of the superheater and other ignition sources. VTS Southampton were alerted to the escalating risk of explosion and fire. They ordered that all ships in the Solent were to return to berth and no ships were to pass Fawley Refinery.

At 1929 hours VTS activated SOLFIRE (Red Alert), the port emergency plan. Solent coastguard (CG) were informed who immediately put the Lee-on-Solent CG helicopter on immediate scramble. All traffic movement on the Solent was to cease for 12 hours.

The Rescue Co-ordination Centre Plymouth put RAF Culdrose and RAF Manston on 15 minute stand-by and established an air exclusion zone of 5 miles radius to 2000 feet around MOBIL PETREL. The Esso Fawley operations room reported that contingency plans were being made to tow the vessel off the berth.

At a conference in the CCR between Esso and Hampshire Fire Brigade representatives and Mobil's Superintendent Manager, priority was given to flooding the main pump room with water to bring the level of oil above the pump shaft bulkhead penetrations thus stopping leakage of oil into the engine-room. It was decided, also, to fill the engine-room with high expansion foam to blanket the high concentration of hydro-carbon gas that had built up in the space. As a result all available high expansion foam generators were mobilized at the ship.

The ship's officers and other personnel essential to the emergency operation were retained on board the ship, but others including 18 crew members were sent ashore. The landing on board of the foam machines and the foam concentrate canisters commenced. Two Hampshire Fire Brigade fire fighters with ship's engineers all wearing SCBA entered the top of the main and forward pump rooms in order to obtain gas level readings and to try to ascertain how much oil had penetrated the spaces. The atmosphere inside the deck entrances to the space was found to exceed the lower explosive limit (LEL).

By 2215 hours the main pump room was being filled through its fixed foam nozzle outlets using shore supplied water. Later, it was decided to attempt an entry into the main pump room to ascertain the oil/water interface. Two fire monitors were used to provide an effective water spray curtain over the area of the pump room entrance as attempts were made to open the door. The space appeared to be under considerable pressure which was probably caused by the flow of water into it and the inability of the displaced gases and air to discharge to atmosphere through the ventilation trunkings, since some openings in the trunks had been submerged by the liquid in the pump room. The pressurisation was apparent when gas escaped through the gaps of the pump room access doors from the main deck. The pumping of water into the pump room was stopped and the pressure relieved when the final dog latch on the deck to pump room door was released and the door opened from a remote position using an attached rope. Meanwhile high expansion foam was being pumped into the engine- room using portable foam eductors and nozzles discharging the foam through the engine-room entrances at the boat deck.

The ship's emergency fire pump was not used since the shoreside water supply was readily available and of adequate pressure. The emergency fire pump would, in any case, not have been of sufficient capacity to cope with the number of monitors and foam machines in use. Also, the hydraulically driven pump was situated at the bottom of the auxiliary pump room where crude oil had flooded from the pipe tunnel. There was a fear that the oil would leak into the sealed shaft glands of the fire pump and that the bearings might overheat presenting an ignition source to the hydro-carbon gas. It was correctly assumed that the crude oil had flooded from the pipe tunnel space into the auxiliary pump room through ventilator trunk openings.

After further consultations between Mobil and the Hampshire Fire Brigade, high expansion foam was applied to the main pump room, the three tunnel access trunks, the auxiliary pump room and the breached Number 2B centre and Number 3 centre cargo tanks. The deck foam monitors were used to achieve an effective water spray curtain so that an initial access to all these spaces was possible in order to place the foam making machines in position.

The objective was to ensure that all damaged compartments, pipe tunnel access trunks, pump rooms and engine-room were brought under inert conditions as quickly as possible.

After approximately five hours of continuous foaming, vapour levels were reduced to 0.5% to 1% LEL in all areas. Monitoring of vapour levels was maintained and foaming operations followed up when necessary.

At 0615 hours on 8 November the air exclusion zone was lifted, the SOLFIRE alert reduced from RED to GREEN and the port opened to ferries. The situation had been stabilized and preparations were made to tow the vessel to an anchorage in the Solent. The movement was delayed until the morning tide of 10 November, after bad weather had abated.

Throughout the incident there was neither fire, pollution nor injury to personnel.

4. CATASTROPHIC FAILURE AND EXTENT OF DAMAGE

A catastrophic structural failure occurred in the area of Number 2B centre and Number 3 centre cargo tanks. The transverse bulkhead dividing the two tanks at frame 82 had collapsed and the main deck and the port and starboard longitudinal bulkheads at Number 2B centre cargo tank had ballooned outwards into the adjacent wing tanks. The pressure on the longitudinal bulkheads was sufficient to buckle the deck frames of the strongly constructed transverse frame units in the wing tanks at frames 83, 84 and 85. The port shell plate had bulged outwards up to a maximum deflection of 167 mms at frame 84.

There was no damage to the inner bottom of any tank or to any other transverse bulkheads. The configuration of the structural damage indicated that there had been a pressure build-up in Number 2B centre cargo tank.

At the time of the failure a simultaneous discharge and ballast operation involving a number of cargo tanks was taking place. Number 3 centre was approximately one third full with crude oil, and Number 2B centre about two thirds full with ballast water.

The collapse of the transverse bulkhead at frame 82 ruptured the attached vertical centre access trunk exposing the contents of the two tanks to the pipe-tunnel. A mixture of cargo oil and ballast water entered the breach in the trunk and drained into the pipe-tunnel. The liquid made its way from the pipe tunnel into the auxiliary pump room through the adjoining ventilation trunking, and into the main pump room by seeping past closed doors separating the two spaces. Both pump rooms filled up to a depth of approximately 10 metres.

The engine-room was flooded to about 4 metres above the inner plates of the inner double bottom; the oil/water mixture having leaked from the main pump room through the bulkhead cargo pump and pump room fan shaft glands.

PART II DISCUSSION

5. CAUSES OF STRUCTURAL FAILURE

5.1 A number of factors were considered to be a possible influence on the type of failure which occurred. These were:

- excessive stresses due to weakened structure or overloading
- explosion of a hydro-carbon gas/air mixture
- over-pressure of Number 2B centre cargo tank during the ballasting operation.

5.2 Excessive Stresses due to Weakened Structure or Overloading

The ship's structure had been surveyed in accordance with the requirements of the Bermudian Authorities and the Classification Society.

Examination of the damaged structure and recent survey reports indicated that the structure had been built to the standard specification of the Classification Society and that its integrity had not been compromised by corrosion or by structural repairs which had been undertaken during the lifetime of the vessel.

There was no evidence found in the ship's logs or in weather reports to indicate that the area bounding the structural failure was subjected to excessive stress levels due to adverse loading and weather conditions.

The hull plate crack discovered in the Number 1 port wing cargo tank between frames 99 and 100 on arrival of the vessel into Rotterdam was remote from the area of structural failure. Although the cause of the crack in Number 1 port wing cargo tank could not be positively determined, it appeared to be an example of structural problems, endemic in the early generation of very large crude carriers, which are identified in the Guidance Manual for the Inspection and Condition Assessment of Tanker Structures, issued by the International Chamber of Shipping and the Oil Companies International Marine Forum on behalf of the Tanker Structure Co-operative Forum. In this particular case the problem closely resembled that shown on page 60 of the 'Guidelines'. A transverse crack had developed across the top and face of a side longitudinal approximately O.5 metres from a transverse web, and had penetrated the hull plating. Approximately one square metre of plate, together with associated internal structure was renewed to the satisfaction of the Classification Society. There was no indication of structural wastage.

On this evidence the crack could not have influenced the structural instability in the region of Number 2B centre cargo tank which resulted in the collapsed bulkhead. The subject of the plate fracture was therefore eliminated from the inquiry.

During MOBIL PETREL's stay in Rotterdam and on crossing to Fawley the hull stresses fell well inside the safe limits due to the distribution of cargo and ballast. On passage, the ship was not subjected to any adverse sea condition which may have caused these limits to be exceeded.

It is concluded therefore, that the catastrophic failure was not due to or influenced by structural weaknesses or by overloading due to weather conditions or patterns of loading of the vessel.

5.3 Explosion of a Hydro-carbon Gas/Air Mixture

The configuration of the collapse of the transverse bulkhead and the distortion of the surrounding structure of Number 2B centre cargo tank indicated that an excessive pressure had developed from inside the tank. A pressure build up to a catastrophic proportion could be due either to an explosion of a hydro-carbon gas/air mixture or as a result of overpressure in the tank due to inadequate venting during the simultaneous discharge operation.

The possibility of a hydro-carbon gas explosion has been eliminated for the following reasons: there was no sign of heat or fire at the time of the incident; later inspection of the vessel did not reveal any heat distorted structure; no soot deposits or scorching of paintwork was found. Inside the damaged centre access trunk hatch, for example, the paint on the steel work was intact but covered with a tar-like brown deposit.

An explosions expert, employed by Mobil to investigate the possibility of an explosion, confirmed that the structural damage was associated with low static forces and concluded that it was inconceivable that the observed patterns of damage could have been caused by an explosion.

The possible existence of a hydro-carbon gas/air mixture coming in contact with a source of ignition was therefore not followed up, so the cause of an over-pressure in Number 2B centre cargo tank was investigated.

5.4 Over-pressure of Number 2B Centre Cargo Tank

To satisfy Fawley Oil Refinery's requirement that gas venting to atmosphere is minimized, the officers followed the normal practice and interconnected all the cargo tanks through the I.G. distribution main, setting the mast riser and tank p/v valves on automatic and shutting the tank vent valves. The demand for I.G. during a simultaneous cargo and ballast operation is dependent on the relative ballast loading and cargo discharge rates; a change in the relative pumping rates would vary the gas pressure in the cargo tanks. Therefore to maintain the pressure within normal limits and to prevent a vacuum being drawn or an excessive pressure build up which would cause structural damage to the vessel, or dilution of the I.G. by air, the I.G. flow rate to the interconnecting tanks and gas main had to be controlled.

The I.G. pressure regulating valve on the I.G. distribution main is designed to control the gas flow to the tanks and maintain the normal operating limits of gas pressure. However, the liquid pressure vacuum (p/v) breaker fitted on the I.G. distribution main, will prevent an uncontrolled pressure rise to beyond the designed pressure of the tanks and pipe-work, but only if the I.G. branch valves for each tank are open. If shut, the tanks being ballasted will not vent sufficiently through their respective p/v valves to prevent over-pressurisation.

A simultaneous cargo and ballast operation was taking place when the catastrophic structural failure occurred. Number 4 wing cargo tanks and Number 3 centre cargo tank were in the process of being discharged using Number 3 main cargo pump (MCP) and Number 4 MCP respectively. Numbers 1 and 2 MCPs were pumping ballast into Number 2B centre cargo tank, and evidence indicates that the I.G. branch valve on Number 2B centre cargo tank was shut during this operation. The instrumentation used to monitor continuously and permanently record I.G. main gas pressure and associated alarm systems did not indicate at any time before the incident a pressure beyond the normal operating limits. This instrumentation was subsequently tested and found to be satisfactory. The water seal in the p/v breaker had not been affected; the seal would have blown out had the I.G. distribution main been subjected to an over-pressure.

It was concluded that the operating range had not been exceeded in the I.G. distribution line during the events leading up to the incident. Over-pressurisation of the Number 2B centre cargo tank could only have occurred if the I.G. branch valve on the tank had remained closed during the ballasting operation.

5.5 Estimated Over-pressure in Number 2B Centre Cargo Tank

The rate of pressure build up in the tank was dependant on the ballast rate of discharge into the tank and the rate of displacement of some tank atmosphere through the p/v valves fitted to the tank and to the vent mast riser, and through the I.G. branch valve, the disc of which, in this case, was corroded and not completely gas tight, thereby allowing some throttling of gas past the closed valve.

A number of assumptions had to be made in the calculation to determine the over pressure. The tank p/v valve was of obsolete design and it was not possible to accurately identify its flow characteristics. Secondly, there was uncertainty over the rate of ballasting into Number 2B centre cargo tank. The ullages taken by ship's staff were for determining how quickly the tank was filling and were not a quantity measurement. There was doubt therefore as to the accuracy of the times recorded and thus the ballasting rates.

The p/v valve on the cargo tanks is designed to allow for the release of a small volume of tank atmosphere caused by thermal variations and an estimated choke point of 1700 to 3100 cubic metres an hour was assumed. The assumed ballast pumping rate was an average of 5000 cubic metres an hour. Leakage of gas past the closed I.G. branch valve was allowed for in the calculation because of its corroded valve disc.

When the vessel was under repair in dry dock as a result of the accident, the Inspector checked the p/v valves on the tank and the respective mast riser which revealed that there was no reason to believe that they would not have operated automatically as expected when the pressure in the tank rose to the designed lifting pressure of the valve.

Since the Chief Officer had experienced difficulty with the mast riser pressure relief valve jacking arrangements when it was required to depressurise the tanks, the Inspector checked the valve and it was proved that the malfunction would not have affected its automatic operation. It was assumed therefore that it operated normally prior to and at the time of the incident.

Taking these assumptions into account, Mobil estimated that the pressure in the tank at the time of the incident was somewhere between 12 and 23 pounds per square inch (psi) gauge.

These results were consistent with those of MAIB whose findings indicated that the over pressure at the time of structural failure was in the range of 10 to 28 psi gauge.

The Classification Society's hydraulic test pressure requirement for a tank of this kind is equivalent to a head of water of eight feet above the deck measured from the side forming the crown of the tank. By the nature of the hydraulic test, on MOBIL PETREL the tank would have been subjected to a hydraulic pressure of eight feet head water gauge (3.46 psi) at deck level, the pressure increasing linearly to a 92.5 foot head water gauge (40 psi) at the inner double bottom level of the tank.

At the time of the incident therefore, the area of the surrounding bulkheads of the tank and deck above it was subjected to a pressure well in excess of the test pressure imposed in that region.

At deck level this over pressure exceeded the test pressure by 3 to 8 times its value.

6. FLOODING OF THE MAIN PUMP ROOM

The oil/water mixture flooded the main pump room through the access doors leading from the space into the pipe tunnel.

The doors were solidly framed and stiffened, and vertically hinged to open into the pump room. The tightness of each door was maintained by neoprene inserted gaskets around the door's edge and eight individual clamps operated from either side of the door.

When the Chief Officer and Firemen examined the pump room soon after the incident they observed no sign of leakage past the doors. The pipe tunnel had a free space capacity of 7000 cubic metres of liquid, and the bottom sill of each door access was 5.3 metres above the bottom shell of the ship. It would have taken some time for the liquid flooding into the pipe tunnel to reach the level of the sill. The investigation team, during the incident, had reported that the doors were shut, but it was later discovered that the doors, although apparently closed and locked were in fact only held in the shut position with one clamp. Manual manipulation of a door held shut by one clamp clearly indicated that the slightest hydraulic pressure would have allowed leakage past the door joints with eventual flooding of the pump room.

It is most probable that the initial investigation team was mistaken in assuming that the doors were fully closed and locked in position. Access to the doors was not easy being situated in a lower recess which had to be reached by a vertical ladder. Lighting was restricted in that area and the team's vision was hampered by the SCBA which they wore. They were also working under very dangerous conditions. It is not surprising therefore, that a mistake may have been made at that time.

Other possible sources of leakage from the pipe tunnel into the main pump room, were investigated but were discounted. In particular the bilge system in that area was examined and found to be in good condition and the valves in the system prevented, as intended, any flooding between compartments.

When MOBIL PETREL was built in 1973 there was no requirement for the segregation of duct keels (pipe tunnels) from the main and auxiliary pump rooms.

The ABS Steel Vessel 1990 Rules require that exits from the pipe tunnel into the main pump room must be fitted with a watertight enclosure. Although these regulations cannot be applied retrospectively to ships built in 1973, MOBIL PETREL satisfies this requirement: the watertight doors as fitted were designed and approved to withstand a full head of water to the main deck.

The 1990 rules provide for the watertight doors to be of the sliding type capable of remote operation from above the main deck (bulkhead deck) but only if the bulkhead in question is a subdivision bulkhead as required by virtue of the assigned freeboard. On MOBIL PETREL the bulkhead separating the main pump room from the pipe tunnel is not required for subdivision purposes.

The approved locking arrangements for the doors posed problems and a simpler single action locking arrangement might have ensured that the doors resisted any leakage, preventing the flooding of the main pump room and the engine-room. If a sliding door had been fitted with remote closing capability, the main pump room and the engine-room might not have flooded.

It is recommended therefore that there should be an internationally agreed requirement that a watertight sliding door operated from a remote position outside the main pump room and above the bulkhead deck be fitted in exits from the pipe tunnel into the main pump room irrespective of any assigned freeboard requirements.

The ABS Rules do not provide for these watertight doors to be kept closed during normal operation of the ship. It is recommended that there should be such a requirement and doors should only be opened for access into the pipe tunnel for a specific purpose such as to open and close valves.

7. FLOODING OF THE ENGINE-ROOM

The ABS report of 4 January 1989 noted that the pump room bulkhead, including the pump drive shaft sealing glands, as fitted, were examined and found to be in a satisfactory condition. There are no maintenance records which indicate work carried out on the glands.

The Classification Society's Regulations require that care must be taken to prevent leaks at the glands of shafts which penetrate gas tight bulkheads. It is left to the attending surveyor to decide on the extent of the inspection. His power is discretionary: he can demand complete dis-assembly of the gland so that a thorough inspection is possible, or decide that a visual inspection is sufficient which may or may not include a water hose test.

A subsequent inspection of the engine-room/pump room bulkhead, indicated that the only source of leakage of gas and liquid was through the cargo pump and pump room fan motor bulkhead glands. Examination of the glands showed clearly that they were in need of repacking.

The Classification Society's annual survey in this case failed to monitor effectively the condition of the glands and as a consequence the glands failed to prevent leakage into the engine-room when the pump room flooded with oil and gas.

A detailed maintenance and survey schedule for pump room bulkhead glands could reduce the risk of failure in the future. These glands are important for the safety and integrity of the engine-room.

8. EVENTS LEADING UP TO THE INCIDENT

8.1 Failure of the Inert Gas Cargo Tank Branch Valves

The cargo tank vent valves and the I.G. branch valves were hand wheel operated through a gear drive mechanism. The valves were opened and closed in the conventional manner: anti-clockwise to open and clockwise to close. The position of the valve was indicated by a marker on the exposed end of the valve spindle.

These indicators were missing on some valves. Also there were no locking arrangements on any of the I.G. branch valves.

The hand wheel and gear mechanism had been replaced by a hand lever on the I.G. branch valves on Number 2B centre and Number 1 starboard wing cargo tanks. [Fig 3]

In Rotterdam, the hand lever on the Number 2B centre cargo tank valve had been broken and its open and closed position was not obvious.

Evidence suggested that the valve position board in the CCR was in use at the time of the cargo operation in Fawley. The I.G. branch valve on Number 2B centre cargo tank was shown on the board to be in the open position at the time of the incident.

In Fawley, the absence of indication as to whether the valve was open or closed caused confusion to the Second Officer. After consultation with his relieving Officer, they both agreed that the valve was open by comparing the sound of gas thought to be flowing past the valve against that sound emitting from another valve known to be open. The Officers may or may not have been mistaken, but the valve was certainly operated inadvertently at some time during the vessel's stay in Fawley.

The I.G. branch valves on Number 2B centre and Number 1 starboard wing cargo tanks had been in a substandard condition since before the last annual survey of the plant and maybe as far back as 1987. The valve operating mechanism of these valves should have been replaced like with like since, because the replacement levers had no locking capability, they were capable of vibrating the valves into a closed or open position. The broken lever on Number 2B centre cargo tank valve exacerbated its poor condition and contributed to an unsafe operation of the I.G. system with catastrophic results. Mobil's view is that in this case it was not a matter of allowing a piece of equipment to deteriorate. The lever on the valve quadrant of Number 2B centre cargo tank valve had simply broken off in Rotterdam and a temporary method of operating the valve was being utilised prior to making permanent repairs.

The I.G. system was fitted under survey by ABS Classification Society. Any change to the equipment in the system, such as the replacement of the valve gear mechanism by a hand lever, should have been approved to the Society's satisfaction. There was no recorded evidence to indicate that this approval had been given. It may be argued that tacit agreement to the changes was given by the Society since their surveyor checked the valves at the annual surveys. ABS and Mobil Shipping Company should have recorded the fact that the specification of equipment fitted to the I.G. system deviated from the original so that other visiting inspectors might have been aware of the changes.

The hand lever on the valve on Number 2B centre cargo tank had corroded to a point of failure with disastrous consequences. Ship's staff were negligent in not reporting the defect to Shore Management and for not ensuring that an effective repair was made before the valve was used in a cargo operation.

No one recognised the danger posed by the sub-standard condition of these valves in the context of the operation being carried out; neither ship's staff, nor Mobil Shore Management nor the surveyors who had inspected the valves during survey of the I.G. system. In addition they ignored the statutory requirement that I.G. branch valves should have locking devices. Also no officer of MOBIL PETREL appreciated his responsibility to ensure that this locking capability existed.

8.2 Recent History of Inspection and Survey of the Inert Gas System.

The vessel was examined by a Department of Transport Surveyor in January 1988 for the purpose of the issue of a short term Cargo Ship Safety Equipment Certificate on behalf of the Bermudian Authorities. The record of survey advised that the I.G. system should be surveyed and certified within 3 months. There was no recorded comment concerning the cargo deck installation of the system.

In April 1988 the ABS Classification Surveyor inspected the vessel in Singapore and a full term Cargo Ship Safety Equipment Certificate was issued by the Bermudian Authorities. Survey included a four yearly special periodic survey of the I.G. system which had been recorded as having been completed in accordance with the Classification Society requirements. The inspection of the I.G. system included internal and external inspection of the system valves, including all the cargo tank I.G. branch valves which were recorded as being in good condition.

In January 1989, the annual safety equipment survey and endorsement of the Safety Equipment Certificate was completed by ABS, again in Singapore and on this occasion the valves were examined externally.

The Department of Transport's Safety Equipment Certificate renewal survey in 1988 and the ABS annual survey for the endorsement of the full term Certificate were, not unusually, conducted whilst the ship was in service and with the I.G. system in operation. Although there can be no excuse for the surveyor missing obvious deficiencies such as those with the I.G. branch valves, there is little opportunity for him to make a thorough check on whether a cargo deck installation is in a good or bad condition. Only when a ship is out of service and gas freed, such as in dry dock, is this thorough check possible.

Reports from the Master to Mobil Shipping management on the condition of the vessel and equipment dated April 1989, June 1989 and November 1989 recorded that the system was in good condition with the exception of the Number 1 I.G. fan casing which had a temporary repair and needed to be renewed. A spare casing was on board waiting to be installed in the next repair period.

The Chief Engineer acknowledged in a report sent to the company in October 1989, that the I.G. system had difficulty in maintaining a supply of gas with a satisfactory level of oxygen.

The vessel was visited in Fawley the day before the incident by an Inspector of the Department of Transport for the purpose of a Port State Control inspection. The nature of the inspection is limited and must accord with the Memorandum of Understanding on Port State Control which embodies the requirements of control procedures in the relevant IMO and ILO resolutions and conventions.

The Port State, in this case the United Kingdom, had no knowledge of the existing condition of the ship and its equipment. The Inspector found that the ship's papers were in order with the exception of records which indicated that the mandatory routine testing of the lifeboats and their launching equipment was overdue. He demanded, correctly, that the tests should be completed satisfactorily before the vessel left Fawley. He was aware of and accepted the Classification Society's approval of the ship going to Falmouth for repairs to its shell plate.

Only a visual inspection of the cargo deck installation would have uncovered a poorly maintained valve. There was nothing to indicate by general impressions and observations on board that such further inspection of the ship and its equipment was necessary.

The Department of Transport advise that particular attention should be paid to tankers for Port State inspection purposes. In addition to this, advice could be extended and priority given to the inspection of cargo deck installations and that maintenance and operational logs should be viewed.

It should be the responsibility of the shipping company to ensure that a clear record is available to the Inspector and Surveyor during their inspections to indicate clearly maintenance and defects that have arisen on the I.G. system and any modes of operation that have been contrary to the instructions in the publication Inert Gas Systems issued by IMO and the International Safety Guide for Oil Tankers and Terminals (ISGOTT).

The Merchant Shipping (Tankers) (EEC Requirement) Regulations 1981 require that the Master of a tanker informs the Port Authority in advance of entering port of matters relating to the safe operation and condition of the vessel, which include the operational condition of the I.G. system.

The Health and Safety (Dangerous Substances in Harbour Areas) Regulations 1987, require that the Terminal Representative (at Fawley, usually the VIO) and a tanker officer complete a Ship/Shore Check List once the vessel arrives in port. The check list shows the main safety precautions to be taken before and during unloading. The two representatives must consult each other and agree the appropriate precautions to be taken by both the ship and Terminal Authorities before cargo operations commence.

The same check list appears in the Code of Practice which accompanies the Dangerous Substances in Harbour Areas Regulations 1987, in ISGOTT and in the IMO publication, Recommendations on the Safe Transport, Handling and Storage of Dangerous Substances in Port Areas. In no case is the I.G. system included. The guidelines in the publications advise that a mutual safety examination of the ship is made by the terminal and tanker representatives. This examination may include a joint visual inspection to assure each other that standards of safety of both the tanker and terminal operation are fully acceptable. In accordance with normal practice at Fawley, Esso provide the Ship/Shore Check List for completion. This list satisfies the requirements of the Dangerous Substances in Harbour Area Regulations and the advice in the ISGOTT and IMO publications, but Esso have additional questions on their list, one of which relates to the condition of the I.G. system.

The Chief Officer of MOBIL PETREL and the VIO completed the Ship/Shore Check List and signed a joint declaration confirming, to the best of their knowledge, the safety of the cargo operation. The VIO also examined the Pre-arrival Check List. He undertook an inspection of the deck installation, but despite the inspection, the faulty I.G. branch valves were not detected.

Esso have since reviewed their inspection procedures to ascertain if any changes are appropriate. As a result inspections have been restructured and manning levels of the Marine Inspection Group (VIO team) have been increased to enable more frequent and regular checks of ships throughout the entire period of operation at the terminal berth.

It is recommended that the Department of Transport should liaise with the Health and Safety Executive to consider whether the precautions in the Ship/Shore Check List should be strengthened by the inclusion of a reference to the I.G. system as required in the Merchant Shipping (Tankers) (EEC Requirements) Regulations 1981, Pre-arrival Check List; and that the IMO and ISGOTT Ship/Shore Check Lists should be amended to include matters concerning I.G. systems. Terminal Operators should review their procedures for onboard inspection of I.G. installations so that defects in the deck installation are revealed.

8.3 Details of Recent Breakdown of the Inert Gas Plant.

Recent failures of the I.G. system had occurred. Prior to the vessel's arrival at Rotterdam the flue gas line from the starboard boiler uptake to the scrubber unit had been patch welded to prevent ingress of air and dilution of the I.G. quality. Temporary repairs had been made to Number 1 I.G. fan casing.

During discharge at Rotterdam, an expansion coupling on the I.G. main distribution line failed, leaking I.G. to the atmosphere.

In Fawley, the cargo operation was delayed by six hours because of the failure of the temporary repair on Number 1 I.G. fan casing and the collapse of the filter bed tray in the scrubber unit.

Repairs in Rotterdam and Fawley were not supervised by the Classification Society.

The I.G. log book indicated that during a concurrent ballast discharge and cargo loading operation at Sidi Kerir in October 1989 problems were experienced in maintaining oxygen levels to within IMO mandatory limits of 5% in the I.G. distribution line. There was no evidence which indicated that the oxygen content of the I.G. in the cargo tanks was higher than the maximum limit of 8% as advised in ISGOTT and by IMO.

The high oxygen content in the I.G. distribution main was probably influenced by air ingress into damaged pipe-work situated between the boiler exhaust gas uptakes and the I.G. fan. Another factor could have been poor combustion in the boilers affected by low steam demand which sometimes occurs at the loading port.

8.4 Operational Routine of Inert Gas System on Sea Passage

Frequent leaks which occurred on the main deck pipe-work of the I.G. system made it impractical to operate with cargo tanks interconnected under a common I.G. blanket on a loaded or ballast passage. It had become accepted practice to isolate the tanks from the I.G. system at the expense of not knowing the true gas pressure in each tank.

The low pressure I.G. alarm was located in the engine-room and the CCR and a pressure gauge was located in the wheelhouse and the CCR to continuously monitor the gas pressure in the I.G. distribution main. The gauge in the wheelhouse had been defective for some time. When the tanks were isolated from the main there was no facility to continuously monitor the I.G. pressure in each tank. A subjective and crude measurement of the pressure in the tanks was achieved by opening the ullage ports and feeling any gas which might have issued from them. These measurements were never recorded in the log book.

A guidance note issued by Mobil Shipping Company and used on MOBIL PETREL and on other ships of the same class in the Company fleet, advised that all I.G. branch valves should be open to interconnect the cargo tanks and I.G. distribution mains during the loaded or ballast passage.

Similar advice is given in ISGOTT which was on board the vessel and available to all the Officers.

Hand pressure gauge points on the I.G. branch lines could have been fitted so that it was possible to check precisely the pressure in each tank. It would have been quite safe to operate with cargo tanks isolated from the I.G. distribution main.

9. EXECUTION OF EMERGENCY PROCEDURES

Mobil responded immediately and effectively to the emergency. Coincidentally the Superintendent Manager was nominated On-Scene manager by Mobil and, had he not been on board at the time would have had to travel from London to the ship in response to the emergency call in order to co-ordinate activities.

Hampshire Fire Brigade were quickly on the scene and proclaimed that a major incident had occurred and dispatched 10 appliances to the refinery and eventually 14 high expansion foam machines and large quantities of foam concentrate.

Esso Fawley Authorities responded by implementing their Category 2 Emergency Incident Plan which relates to emergencies on site which are beyond the scope of Esso site personnel.

The New Forest District Council emergency contingency plan was put into action and police, ambulance services and hospitals were alerted.

The Solent area emergency plan (SOLFIRE) was set in motion and Lee-on-Solent Coastguard and the Rescue Co-ordination Centre, Plymouth co-operated during the emergency activities.

The Superintendent Manager worked closely and effectively with the Hampshire Fire Brigade and the Esso Authorities. The successful execution of the emergency procedures was, in no small way, due to the co-operation between the three parties and the participation of the ship-board staff who worked under arduous and hazardous conditions.

Three members of the Hampshire Fire Brigade were awarded commendations by their Chief Fire Officer for outstanding work in that, wearing SCBA, they entered spaces known to have flammable atmospheres in order to establish the amount of crude oil which had flooded into the pump rooms and the amount of gas concentrations in these spaces and in the engine-room, and to check for the existence of heat within and around these areas.

The Chief Officer led a SCBA team into the bottom of the main pump room knowing that the pipe tunnel had flooded with crude oil and that leakage into the pump room and an explosion were distinct possibilities. The Superintendent Manager needed to know the conditions that prevailed in the pump room so that a careful assessment could be made of the situation. Entry into and inspection of the space was therefore essential. The Chief Officer's actions should, like those of the fire brigade officers, be recognised and he should be commended.

Once it was realised that the gas concentrations were reaching dangerously high levels in the engine-room, the plant had to be shut down quickly so that the risk of explosion and fire was reduced. Prompt action was necessary by the Engineers who responded effectively to the demand, willingly discharging their duties in an efficient manner under dangerous conditions.

The Engineers were hampered in shutting down the machinery and in their escape from the engine-room because it was in darkness. It was expected that the emergency generator would supply electrical lighting power automatically once the main generator supply had been isolated. The emergency generator is designed to power emergency lighting and electrical equipment required by statute as well as other electrical machinery and lighting considered additional to emergency needs.

However, the electrical interlocking arrangement between the main and emergency switchboard failed. The automatic initiation relay, designed to close the emergency generator main circuit breaker did not operate when main power was lost. The circuit breaker had to be closed by hand and lighting on the ship was re-established, but was soon lost again when the diesel drive stopped because of a faulty high jacket cooling water temperature sensor. It was not possible to reinstate electrical power to the vessel for the rest of the emergency period.

A regular programme of testing of the automatic interlocking sequence of closure of the emergency switchboard circuit breakers, and the routine running of the emergency generator on load for a period of time might have ensured the reliability of the equipment during the emergency.

The automatic circuit-breaker was subsequently examined in the ship-repair yard and no fault was found. It was cleaned, returned to place, and tested satisfactorily.

The vessel was towed to a safe anchorage off Lee-on-Solent on 10 November, finally departing under tow in ballast, bound for Lisnave Dry Dock, Lisbon on 21 November. A total of 1,236 attendances were made by Hampshire Fire Brigade personnel over the whole period up to that time.

127,500 litres of high expansion foam were provided, of which 86,000 litres were used, to contain flammable gases within the breached compartments, until the liquid had been pumped out and the spaces gas freed.

10. ACTIONS TAKEN BY MOBIL TO PREVENT RECURRENCE

Mobil Shipping Company investigated the incident and certain measures have been taken and recommendations made in order to prevent a similar occurrence in the future:

The Mobil Investigating Officer has recommended that a training programme should be implemented to improve Officers' management skills and commitment.

The old central cargo tank gauging system was replaced by a radar type system.

The tank venting system has been replaced by two high velocity vents fitted to each tank with one vent only on each of the three small slop tanks. The through-put of each vent is 5000 cubic metres at 1500 mm water gauge. The system was approved and surveyed by ABS. A remote pressure sensor is fitted to each cargo tank so that the tank pressure can be constantly monitored.

The Master has received written advice as to the maximum loading rate permitted in each tank. This information should be permanently and clearly displayed in the CCR.

The I.G. system on the ship was completely overhauled whilst in Lisbon.

In order to avoid a similar incident on other ships in their fleet, procedures have been developed and implemented for monitoring and controlling the status of all I.G. and vent valves. In addition, and following a review of systems installed throughout their fleet, Mobil Shipping Company developed a number of programmes to upgrade and enhance equipment on other ships. These programmes, which are now well advanced, cover the installation of remote tank pressure monitoring systems on all inerted ships, the installation of individual tank high velocity vents on many ships, and the replacement of old central gauging systems by radar type systems.

PART III CONCLUSIONS

11 FINDINGS

11.1 The over pressure on Number 2B centre cargo tank occurred during a simultaneous ballast and cargo discharge operation under closed venting conditions because of a defective I.G. branch valve. The valve did not indicate clearly its open and closed position and had been closed incorrectly resulting in a cargo tank rupture and release of dangerous concentrations of hydro-carbon gas into the atmosphere and the flooding of other compartments in the vessel.

11.2 Ship's staff, aware that the valve was defective, made no attempt to repair or replace it or take appropriate precautions which might have prevented its unintentional operation. The officers did not realise the danger that existed when using a valve in this condition.

11.3 The tank over-pressurised when two cargo pumps were used to ballast the tank. Calculations showed the estimated flow limit through the tank p/v valve to be within the range 1700 to 3100 cubic metres per hour. The maximum ballast water discharge rate of each cargo pump is 4200 cubic metres per hour. The pressurisation of Number 2B centre cargo tank was inevitable for any ballast rate greater than the tank p/v valve flow limit; thus the calculations demonstrated that even if only one pump had pressurised the tank, pressure would still have reached destructive levels.

The use of two cargo pumps on Number 2B centre cargo tank was not therefore a contributory factor influencing events leading up to the accident.

11.4 The pressure relief system was not fail-safe as the tank p/v valve was not designed to allow sufficient flow to avoid pressurisation.

11.5 Mobil Shipping Company have a well structured management system to operate their ships yet unsafe practices in the operation of the I.G. system had become acceptable to the ship's officers. With the Tanker Manual, the Company had an excellent set of procedural instructions but the practice advised in it was not implemented on MOBIL PETREL.

12. FURTHER OBSERVATIONS

12.1 In the incident on MOBIL PETREL over-pressurisation was not caused by excessive ballasting rate. However, there have been several reported incidents of buckling of structures in tankers during ballasting operations, some of which have been investigated by the Salvage Association. The Association's Casualty Information Retrieval System reveals that in the five years 1984 to 1988, 36 such incidents occurred.

Due to the serious nature of casualties of this type, and the implications for the environment, provisions to avoid over-pressurisation of tanks used for ballast should be investigated.

One method to consider is the possibility of a sensor alarm measuring a gas/air flow-rate in the tank p/v valve advising the CCR that a cargo tank is experiencing excessive pressures approaching tank design pressure limitations. The tank p/v valve should be capable of allowing sufficient flow of gas/air through to avoid an over-pressurisation of the tank for the maximum allowable ballast water loading rate. In the case of MOBIL PETREL, it should be at least 4200 cubic metres per hour.

12.2 During the course of the investigation it was found that the I.G. system had been regularly operated at sea on cargo and ballast voyages in a way that was contrary to recognised company, international and national instructions. Safe monitoring of the pressure of the atmosphere in each tank could not take place.

The tanks should have been left open to the I.G. system to ensure that the pressure and any loss of gas in the tanks could be carefully monitored. Loss of I.G. pressure from the tanks is inevitable because of air and sea temperature changes, and occasional topping up of the tanks with I.G. should have been normally anticipated.

It was convenient to the officers to operate in the way they did. Persistent leaks on the I.G. distribution main would have entailed frequent topping up of the I.G. blanket had the tanks been made common.

It was important therefore, to ensure that fittings on the I.G. system were gas tight so that the system was not operated more than was necessary. Adequate maintenance was not provided to ensure that leakage did not occur.

12.3 In any ship, responsibility for ensuring that plant is operated and maintained safely and efficiently rests with the owners who are in turn dependent upon the ship's officers. All defects which cannot be fully rectified on board should be reported by the ship to management and to the classification society. This was not done in MOBIL PETREL.

The I.G. system had been surveyed by ABS for the purpose of ensuring that it satisfied the relevant regulations of the Society and the SOLAS Convention. The Department of Transport surveyed the installation in February 1988 and a three month short term Safety Equipment Certificate was issued. To issue a certificate of this kind the surveyor must be satisfied that the I.G. system is functioning as required by regulation, and that its condition will remain satisfactory for a duration of 3 months.

The survey was conducted, as on many occasions on other similar ships, when the vessel was in service and the I.G. system in operation. A detailed check on the installation was not therefore possible and the surveyor was dependent on the ship's operational logs and maintenance reports to help in his assessment of the plant.

MOBIL PETREL's I.G. log book is a well documented check list and was available for inspection by visiting surveyors and inspectors but it did not indicate clearly that all was not well with the I.G. system.

Clear and concise records should be designed so that Surveyors, Inspectors and Shore Management alike can easily ascertain that the state of performance and operation satisfies national, international and company regulations.

These records are essential under the circumstances which prevail today where safety equipment renewal surveys are conducted under severe constraints with the ship in service and not gas free and having limited time in port, so that detailed inspection of the I.G. system is impossible.

13. RECOMMENDATIONS

Note **Action on the Recommendations addressed to the Government of Bermuda is already in hand.**

1. The Government of Bermuda should approach the International Chamber of Shipping (ICS), Oil Companies International Marine Forum (OCIMF) and the International Association of Ports and Harbours (IAPH) to include in the ISGOTT publication advice supporting the IMO Resolution A647(16)that:

   Tankers should have on board a concise record of inspection of defects affecting safe and efficient operation of the I.G. system and other deck installations and of repairs carried out so that visiting Port State Inspectors, Surveyors and Shore Management can easily ascertain that the state of performance and operation of the I.G. system is in accordance with national, international and company regulations.

2. The Government of Bermuda should approach the Department of Transport to liaise with the HSE, IMO and the authors of the ISGOTT publication, (OCIMF, ICS and IAPH), to consider whether their published Safety Ship/Shore Check list should be strengthened by inclusion of a reference to the I.G. system.

3. The Safety of Life at Sea Convention 1974, its amendments and its 1978 Protocol was extended to Bermuda in June 1988.

   Bermuda have not yet implemented the provision in the 1978 Protocol with regard to Regulation 11, Maintenance of Conditions after Survey.

   The U.K. administration have included this provision in Merchant Shipping (Cargo Ship Safety Equipment Surveys) Regulations 1981.

   The Government of Bermuda should seek to extend the provisions in Regulation 11 to their own Regulations.

4. The Chief Officer, in leading a team of fire fighters into the main pump room in order to investigate the conditions which existed in the space soon after the incident, performed an essential duty at the risk of his own life. It is recommended that he should be commended by the appropriate authorities for his bravery.

5. The Government of Bermuda should approach the Department of Transport to seek international agreement through the appropriate Agencies:

5.1 To require that watertight doors fitted in pipe tunnels giving access to main pump rooms be of the sliding type with remote operation capability from outside the main pump room above the bulkhead deck;

5.2 That the watertight doors be kept shut during normal operation of the vessel except where access into the pipe tunnel is required for specific purposes;

5.3 To have provision for monitoring I.G. pressure in individual cargo tanks of oil tankers;

5.4 To have a sensor measuring alarm device advising the CCR that a cargo tank is experiencing excessive pressure approaching tank design pressure limitations;

5.5 To have precise and detailed requirements for the inspection and repair of engine-room bulkhead/cargo pump room penetrations.

5.6 To have precise and detailed requirements for the overhaul and workshop testing of p/v valves.

6. The Marine Surveyors of the United Kingdom and Bermudian Administrations cannot fully inspect the I.G. system for the purpose of the issue of the SOLAS Safety Equipment Certificate because of insufficient downtime of tankers in service.

The two Administrations should devise instructions and survey procedures for surveyors so that the I.G. system is fully inspected to their satisfaction.

7. Taking into account SOLAS requirements for different types of ships, their year of build and whether automatic or manual start or transitional batteries are provided, the Department of Transport should advise industry that where practical, in emergency power installations, the generator should be tested on load and the interlocking main circuit breakers tested on a regular basis.

8. The Department of Transport advise Marine Surveyors of the Marine Directorate of the need for particular attention to be paid towards tankers for Port State Control inspection purposes.

This advice should be extended: priority should be given to the inspection of cargo deck installations, and maintenance and operational logs should be viewed.

REFERENCES

1. Merchant Shipping (Fire Protection) (Ships Built Before 25 May 1980) Regulations 1985. (S.I. 1985 No. 1218).

2. IMO International Convention for the Safety of Life at Sea 1974 and the Protocol of 1978 relating to the Convention.

3. Tanker Structure Co-operative Forum Project 200 - Structural Details: Report on the Work of Project 200 Group.

4. Rules for Building and Classing Steel Vessels 1990: American Bureau of Shipping.

5. International Safety Guide for Oil Tankers and Terminals: Third Edition.

6. IMO Inert Gas Systems 1983 and 1990 Editions.

7. Health and Safety (The Dangerous Substances in Harbour Areas) Regulations 1987. (S.I. 1989 No. 37).

8. Health and Safety Commission approved Code of Practice: Dangerous Substances in Harbour Areas.

ABBREVIATIONS

ABS	American Bureau of Shipping
BP	[length] between perpendiculars
CCR	Cargo Control Room
COW	Crude Oil Washing [a tank cleaning system]
IG	Inert Gas
IMO	International Maritime Organization
ISGOTT	International Safety Guide for Oil Tankers and Terminals
LEL	Lower explosive limit
MCP	Main Cargo Pump
SCBA	Self-contained Breathing Apparatus
SOLAS	[International Convention on] Safety of Life at Sea
VIO	Vessel Inspection Officer
VTS	Vessel Traffic Service